

[0001] ADAPTIVE UPLINK/DOWNLINK TIMESLOT ASSIGNMENT IN
A HYBRID WIRELESS TIME DIVISION MULTIPLE ACCESS/CODE
DIVISION MULTIPLE ACCESS COMMUNICATION SYSTEM

[0002] This application claims priority from Provisional Application No. 60/221,009, filed July 27, 2000.

[0003] BACKGROUND

[0004] The present invention relates generally to resource allocation in wireless hybrid time division multiple access/code division multiple access communication systems. More specifically, the invention relates to assigning uplink and downlink timeslots in such systems.

[0005] Figure 1 depicts a wireless communication system. The system has a plurality of base stations 30_1 - 30_{11} . Each base station 30_1 communicates with user equipments (UEs) 32_1 , 32_3 , 32_4 in its operating area or cell. Communications transmitted from the base station 30_1 to the UE 32_1 are referred to as downlink communications and communications transmitted from the UE 32_1 to the base station 30_1 are referred to as uplink communications.

[0006] In addition to communicating over different frequency spectrums, spread spectrum code division multiple access (CDMA) systems carry multiple communications over the same spectrum. The multiple signals are distinguished by their respective chip codes (codes). To more efficiently use the spread spectrum, some hybrid time division multiple access (TDMA)/CDMA systems as illustrated in Figure 2 use repeating frames 34 divided into a number of timeslots 36_1 - 36_n such as fifteen timeslots. In time division duplex (TDD) systems using CDMA, a timeslot is used either solely for downlink or uplink communications in a cell. In such systems, a communication is sent in selected timeslots 36_1 - 36_n using selected codes. Accordingly, one frame 34 is capable of carrying multiple communications distinguished by both timeslot 36_1 - 36_n and code. The use of a single code

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in a single timeslot with a spreading factor of sixteen is referred to as a resource unit. Based on a communication's bandwidth requirements, one or multiple resource units may be assigned to a communication.

[0007] One problem in such systems is cross cell interference as illustrated in Figure 3. A second cell's base station 30_2 sends a downlink communication 40 to a second cell's UE 32_2 in a certain timeslot. In the same timeslot, an uplink communication 38 is sent from a first cell's UE 32_1 . The uplink communication 38 may be received by the first cell's base station 30_1 at an unacceptable interference level. Although the second cell's base station 30_2 is further away than the first cell's UE 32_1 , the higher effective isotopically radiate power (EIPR) of the second cell's base station 30_2 may result in unacceptable interference at the first cell's base station 30_1 .

[0008] Also shown in Figure 3 is cross interference between UEs $32_1, 32_2$. An uplink signal 38 from a first cell's UE 32_1 will create unacceptable levels of interference to a downlink communication 40 in the same timeslot received by the second cell's UE 32_2 , due to their close proximity.

[0009] Accordingly, there exists a need for reducing cross cell interference.

[0010] SUMMARY

[0011] A particular cell of a hybrid time division multiple access/code division multiple access communication system has a base station and a plurality of user equipments. Timeslots having unacceptable interference for the uplink are estimated. Timeslots having unacceptable interference for the downlink are estimated. An availability list is produced. The availability list indicates available uplink and downlink timeslots having acceptable interference levels. Uplink and downlink timeslots are assigned using the availability list.

[0012] BRIEF DESCRIPTION OF THE DRAWING(S)

[0013] Figure 1 is a wireless spread spectrum CDMA system.

- [0014] Figure 2 illustrates timeslots in repeating frames.
- [0015] Figure 3 illustrates cross cell interference.
- [0016] Figure 4 is an availability list.
- [0017] Figure 5 is a flow chart for generating an availability list using base station to base station (BS-BS) and user equipment to user equipment (UE-UE) interference cells.
- [0018] Figure 6 is an example of a cross interference cell list.
- [0019] Figure 7 is a table showing a hypothetical timeslot allocation for each cell.
- [0020] Figure 8 is an availability list for cell 1 constructed using Figures 6 and 7.
- [0021] Figure 9 is a flow chart for producing an availability list using only BS-BS interference cells.
- [0022] Figure 10 is an illustration of a BS-BS cross interference list.
- [0023] Figure 11 is a flow chart for producing an availability list using only UE-UE interference cells.
- [0024] Figure 12 is a UE-UE cross interference list.
- [0025] Figures 13 and 14 are flow charts using base station and user equipment interference measurement to determine timeslot availability.
- [0026] Figure 15 is an illustration of a user equipment specific availability list.
- [0027] Figures 16 and 17 are flow charts for using only interference measurements to determine timeslot availability.
- [0028] Figures 18, 19 and 20 are flow charts for determining timeslot availability using hybrid approaches.
- [0029] Figure 21 is a flow chart of a timeslot assignment approach.
- [0030] Figure 22 is a flow chart of availability list updating.
- [0031] Figure 23 is the updated table of Figure 7.
- [0032] Figure 24 is an updated availability list for cell 7 based on Figure 23.
- [0033] Figure 25 is a centralized architecture embodiment.
- [0034] Figure 26 is a decentralized architecture embodiment.

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[0035] DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0036] Although the following describes timeslot assignment in context of a TDD/CDMA system, the same timeslot elimination procedures and availability lists can be applied to a hybrid TDMA/CDMA system where uplink and downlink communications occur in the same timeslot in a cell.

[0037] Figure 4 illustrates an availability timeslot list 76. Along the horizontal axis, each timeslot is listed as S1, S2,..., SN. Along the vertical axis, each cell, listed here by the subscript of its associated base station's reference number, is listed for both the uplink and downlink. Each row indicates the timeslot availability for either the uplink or the downlink for a cell. Timeslots not available are indicated with an "X". Available timeslots are left empty.

[0038] One procedure for generating the availability list is shown in Figure 5 and is explained in conjunction with Figures 6, 7 and 8. Initially, the cross interference between each cell pair is measured. Initially, base station 30₁-30₁₁ to base station 30₁-30₁₁ (BS-BS) interfering cells are determined, step 77. BS-BS interfering cells are cells where a base stations 30₁-30₁₁ transmissions interfere with another base stations 30₁-30₁₁ reception.

[0039] Each cell determines its BS-BS interfering cells by estimating interference from the other cells. One approach estimates the BS-BS interfering cells using pre-measured link gains between the base stations 30₁-30₁₁. If the estimated interference exceeds a threshold, the base stations' cells are considered BS-BS interfering cells, step 77. Based on the threshold comparison, BS-BS interfering cells are determined and stored in a cross interference cell list 84 as illustrated in Figure 6. The vertical axis of the cross interference cell list 84 has each cell. The horizontal axis has potential cross interfering cells. A cell that BS-BS interferes with another cell is marked in the appropriate box by an "I", step 79. For example, since communications in cell 2 cross interfere with cell 1, the first row, second column box is marked with an "I." Since a cell does not interfere with itself, these boxes are marked by an "X."

[0040] Additionally, cells where UEs 32_1 - 32_n may interfere with other UEs 32_1 - 32_n are determined, step 78. Due to the relatively low EIPR of UEs 32_1 - 32_n , the UE-UE interfering cells are in close geographic proximity, such as being adjacent. One UEs 32_1 uplink transmission can interfere with a neighboring cell's UE reception, as shown in Figure 3. Since cells with close geographic proximity may have UEs 32_1 - 32_n which may interfere with each other, these cells are also listed as interfering cells. In Figure 6, the UE-UE interfering cells which were not BS-BS interfering cells are marked with an "I*", step 79.

[0041] Using the cross interference cell list 84, for each cell, the potential cross interference cells are determined, step 78. For a particular cell in the vertical axis, each cell in the corresponding row marked with an "I" or "I*" is a cross interference cell. For instance, cell 1 is potentially cross interfered by cells 2, 3, 5, 6, 9 and 10. For each cross interference cell, the timeslot allocation is determined. For instance, using the hypothetical timeslot allocation of table 86 of Figure 7, cell 2 is allocated downlink timeslots 1 and 2 and uplink timeslot 9. For each downlink timeslot allocated in a cross interference cell, a corresponding uplink timeslot is eliminated, step 80. To illustrate using Figure 6, 7 and 8, for cell 1, cell 2's allocated downlink timeslot 1 eliminates timeslot 1 from cell 1's available uplink timeslots as shown by an "X" in cell 1's availability list 88 of Figure 8.

[0042] For each uplink timeslot allocated in a cross interference cell, a corresponding downlink timeslot is eliminated, step 82. To illustrate for cell 1, cell 2's uplink timeslot 9 eliminates that timeslot from cell 1's possible downlink timeslots as shown in cell 1's availability list 88. After eliminating the appropriate timeslots due to the cross interference cells, an availability list 76 for each cell is produced, step 90. As a result, uplink and downlink timeslots used in cross inference cells are made unavailable reducing cross cell interference.

[0043] To relax the assignment conditions, either only the BS-BS interfering cells or only the UE-UE interfering cells are considered. These approaches may lead to freeing up

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more resources for each cell. However, the looser criteria may result in unacceptable interference levels with respect to some users.

[0044] Figure 9 is a flow chart for producing an availability list using only BS-BS interference cells. The BS-BS interference cells are identified, step 122. A BS-BS cross interference list 132 is produced, such as in Figure 10. If a cell uses a timeslot for the uplink, that slot is eliminated for use by BS-BS interfering cells for the downlink, step 126. Conversely, if a cell uses a timeslot for the downlink, that slot is eliminated for use by BS-BS interfering cells for the uplink, step 128. A list of available timeslots is produced for each cell, step 130. Although this approach more aggressively uses the systems resources, unacceptable downlink interference may be suffered by some users.

[0045] Figure 11 is a flow chart for producing an availability list using only UE-UE interference cells. The UE-UE interference cells are identified, step 134. A UE-UE cross interference list 142 is produced, such as in Figure 12. If a cell uses a timeslot for the uplink, that slot is eliminated for use by UE-UE interfering cells for the downlink, step 136. Conversely, if a cell uses a timeslot for the uplink, that slot is eliminated for use by UE-UE interfering cells for the downlink, step 138. A list of available timeslots for each cell is produced, step 140. This approach may result in unacceptable uplink interference levels for some users.

[0046] Another approach for determining available timeslots uses interference measurements of timeslots, such as by interference signal code power (ISCP). The interference measurements may be taken at the base stations 30_1 - 30_{11} , UEs 32_1 - 32_n or both.

[0047] Figure 13 is a flow chart using base station and UE interference measurements to determine available timeslots for each UE 32_1 - 32_n . For a particular cell, the interference level in each timeslot is measured at the base station 30_1 , step 144. Each of the cell's UEs 32_1 , 32_3 - 32_4 also measure interference levels in each timeslot, step 146. The timeslot interference measurements by the base stations are used to determine the availability of

uplink timeslots. The downlink timeslot availability is determined on a UE by UE basis (UE specific basis).

[0048] For the uplink, if the base station's measured interference exceeds a threshold in a timeslot, that timeslot is eliminated for the uplink, step 148. For the downlink, each UE 32_1 , 32_3 , 32_4 eliminates downlink timeslots for its use, if that UE's interference measure exceeds a threshold, step 150. An availability list 154 is produced showing the available uplink timeslots and the available downlink timeslots for each UE as illustrated in Figure 15, step 152.

[0049] Although two cells are adjacent, the location of specific UEs 32_1 - 32_n in the cells may be distant. To illustrate using Figure 1, cell 1 and cell 2 are adjacent. However, a UE 32_4 is distant from cell 2. Accordingly, if UE 32_2 in cell 2 uses a slot for uplink, it will most likely not interfere with the downlink reception of UE 32_4 . However, UE 32_2 uplink transmissions would likely interfere with UE 32_1 downlink transmissions. As a result, a more aggressive resource allocation is available using a UE specific availability list 154. One drawback is the increased signaling required. Due to UE mobility and other cells' reassignments, the interference measurements must be updated and signaled to the base station 30_1 - 30_{11} on a frequent basis.

[0050] Figure 14 is a flow chart using base station and UE interference measurements to determine non-UE specific available timeslots. The base station 30_1 measures the interference in each timeslot, step 144, and so does each UE 32_1 , 32_3 , 32_4 , step 146. For the uplink, if the base station measured interference exceeds a threshold in a timeslot, that timeslot is eliminated, step 148. For the downlink, if any of that cell's UEs measured interference in a timeslot exceeds the threshold, that timeslot is eliminated for the downlink, step 156. Using the eliminated timeslots, an availability list 88 for each cell is produced, such as per Figure 8. Since the UE measurements are effectively combined, missing UE interference measurements are not critical to resource unit assignment.

[0051] Figures 16 and 17 are flow charts using only UE interference measurements to determine available timeslots. In a cell, each UE measures the interference in each timeslot, step 160. For the uplink, if any UE interference measure exceeds the threshold, that timeslot is eliminated for the uplink, step 160. Alternately, to reduce the number of eliminated uplink timeslots, only the timeslots where most of the UEs have unacceptable interference are eliminated from the uplink, step 160. If only a few UEs report unacceptable interference, it is assumed these UEs are at the fringe of the cell and are not representative of the overall cell conditions.

[0052] Using a UE specific assignment approach as in Figure 16, each UE 32₁, 32₃, 32₄ has its own set of available downlink timeslots, such as per Figure 15. For each UE 32₁, 32₃, 32₄, a downlink timeslot is eliminated, if that UE interference measurement on the timeslot exceeds a threshold, step 164. A UE specific availability list 150 is produced, step 166.

[0053] A non-UE specific approach is shown in Figure 17. If any UE or most UEs' interference measurement exceeds a threshold in the timeslot, that timeslot is eliminated for the downlink, step 168. An availability list 88, such as in Figure 8, is produced for the entire cell.

[0054] Figures 18, 19 and 20 are timeslot availability determination approaches, using hybrid BS-BS interference, UE-UE interference and interference measurement approaches. Figures 18 and 19 use BS-BS interference cells and UE interference measurements. The BS-BS interfering cells are determined, step 172. Each UE 32₁, 32₃, 32₄ measures the interference in each timeslot, step 174. For the uplink, timeslots are eliminated, if a BS-BS interfering cell uses it for the downlink, step 176.

[0055] Downlink availability is determined on a UE by UE or a collective basis. Using a UE by UE basis per Figure 18, each UE 32₁, 32₃, 32₄ compares each timeslot interference measurement to a threshold. If a timeslot measurement exceeds the threshold,

that timeslot is eliminated for that UE $32_1, 32_3, 32_4$ in the downlink, step 178. A UE specific availability list 150, such as Figure 15, is produced, step 180.

[0056] Using a collective basis per Figure 19, if any UE timeslot interference measurement exceeds a threshold, that timeslot is eliminated for the downlink for the cell, step 182. An availability list 88, such as Figure 8, is produced, step 184.

[0057] Figure 20 uses UE-UE interference cells and base station interference measurements. A cell's base station 30_1 measures the interference levels in each timeslot, step 186. UE-UE interfering cells are identified, step 188. For the uplink, eliminate uplink timeslots, if that timeslot's interference exceeds a threshold, step 190. For the downlink, a downlink timeslot is eliminated, if a UE-UE interfering cell uses it for the uplink, step 192. Based on the eliminated timeslots, an availability list 88, such as Figure 8, is produced.

[0058] For sectorized cells, the cross interference list and availability lists 84 are constructed for each sector within the cells. The cross interference between all cell's sectors is determined. Although the following discussion focuses on non-sectorized cells, the same approach also applies to sectorized cells where the assigning is performed on a per sector basis instead of a per cell basis.

[0059] Using the availability list 76, each base station 30_1-30_n is assigned timeslots to support its communications using the procedure of Figure 21. Initially, a request for an additional allocated timeslot or timeslots is made, step 92. Referring to that base station's availability list 76, corresponding available timeslots are assigned. To illustrate using the availability list 88 of Figure 8, the base station 30_1 requires both an additional allocated downlink and an uplink timeslot. The available uplink timeslots are slots 4 and 7-16 and the available downlink timeslots are slots 1-3, 5, 6, 8, 10-13 and 16. One uplink timeslot and downlink timeslot will be assigned out of the corresponding available downlink and uplink timeslots. If a UE specific availability list 150 is used, the downlink assignment is based on the UE 32_1-32_n requiring the downlink resource unit(s).

[0060] Since the base stations 30_1 - 30_n need to dynamically assign and release timeslots due to varying uplink/downlink demand, the information in the availability list 76 requires updating. For approaches using interference measurements, the updates are performed by updating the measurements and the lists.

[0061] For BS-BS and UE-UE approaches, this procedure is shown in Figure 22. Initially, the cross interference cells are identified for each assigned or released timeslot, step 96. For each assigned downlink timeslot, the corresponding timeslots in the cross interference cells are eliminated for the uplink, step 98. Conversely, if the uplink timeslot is assigned, the corresponding timeslots in the cross interference cells for the downlink are eliminated, step 100. To illustrate using Figures 23 and 24, the base station 30_6 associated with cell 6 assigns timeslot 7 for the downlink, "D*", and timeslot 8 for the uplink, "U*", as indicated in table 106 of Figure 23. The cross interference cells are cells 1, 2, 5 and 7. As shown for cell 7's availability list 107 of Figure 24, timeslot 7 is eliminated for the uplink and timeslot 8 is eliminated for the downlink, both marked as "X*".

[0062] If a downlink timeslot was released, the corresponding timeslots in the cross interference cells are freed for the uplink unless unavailable for other reasons, such as being used as a downlink timeslot in another cross interference cell, step 102. For instance, if timeslot 6 of cell 6 is released as indicated in table 106 as "D**", cell 1's uplink timeslot 6 is not made available. Cell 9 is a cross interference cell to cell 1, which also uses downlink timeslot 6. By contrast, for cell 7, the release of downlink timeslot 6 frees the cell for uplink communications as shown in cell 7's availability list 108 by an "R." If an uplink timeslot was released, the corresponding timeslots in the cross interference cells are freed for the downlink unless unavailable for other reasons, step 104.

[0063] One approach for using uplink/downlink timeslot assignment is shown in Figure 25 using a centralized architecture. The radio network controller (RNC) 110 has a resource allocation device 11 to assign or release a timeslot based on user demand. If assigning, the resource allocation device 116 in the RNC 110 assigns an appropriate timeslot

using availability list 76, stored in its memory 117, per the procedure of Figure 21. The selected timeslots and channel codes are communicated to the base station 30_1-30_N and UEs 32_1-32_N , via the node-B timeslot assignment and release device 112_1-112_n . If releasing a timeslot, the RNC resource allocation device 116 releases that timeslot and updates the availability list 76. Accordingly, updating of the availability list 76 is centralized by occurring at the RNC 110.

[0064] Another approach for uplink/downlink timeslot assignment is shown in Figure 36 using a decentralized architecture. Each node-B 122_1-122_N has its own timeslot controller 120_1-120_n . When a timeslot assignment and release device 112_1-112_n requests timeslots for a communication, the node-B's timeslot controller 120_1-120_n selects an appropriate timeslot from its availability list 76, as stored in its memory 121_1 . The stored availability list 76 to reduce its size may only contain the available timeslots for that node-B's cell(s). Conversely, the stored availability list 76 may contain the availability for all the RNC's cells. The decentralized approach allows for faster updates.

[0065] The selected timeslot is assigned to the communication by the timeslot assignment and release device 112_1-112_n . To update the lists 76, that node-B 122_1-122_n updates its list 76. The assigned and released timeslots are also sent to the RNC 110. The RNC 110 directs the appropriate timeslot update information to the other cells. The timeslot information either contains an updated availability list 76 or merely the changes to the list 76. If only the changes are sent, each cell's controller 120_1-120_n updates its own availability list 76 with that information. The type of timeslot information sent is based on the processing and signaling requirements of the system.

[0066] Assigning uplink/downlink timeslots is adaptable to systems supporting differing signaling rates. For systems supporting only slow network signaling, the allocated timeslot information is updated on a daily basis using a statistical analysis of the uplink/downlink demand. Since communication traffic varies during the day, a faster update rate performs better and is preferred. For medium speed network signaling, the updating is

performed periodically ranging from a fraction of an hour to several hours. Medium speed network signaling also uses statistical analysis but over a shorter time period. For fast network signaling, the allocated timeslots are updated on a per call basis or frame basis. Once a timeslot is assigned or released, the appropriate lists are updated. The fast network signaling allocates timeslots on an as needed basis. As a result, it more efficiently uses the system's resources.

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